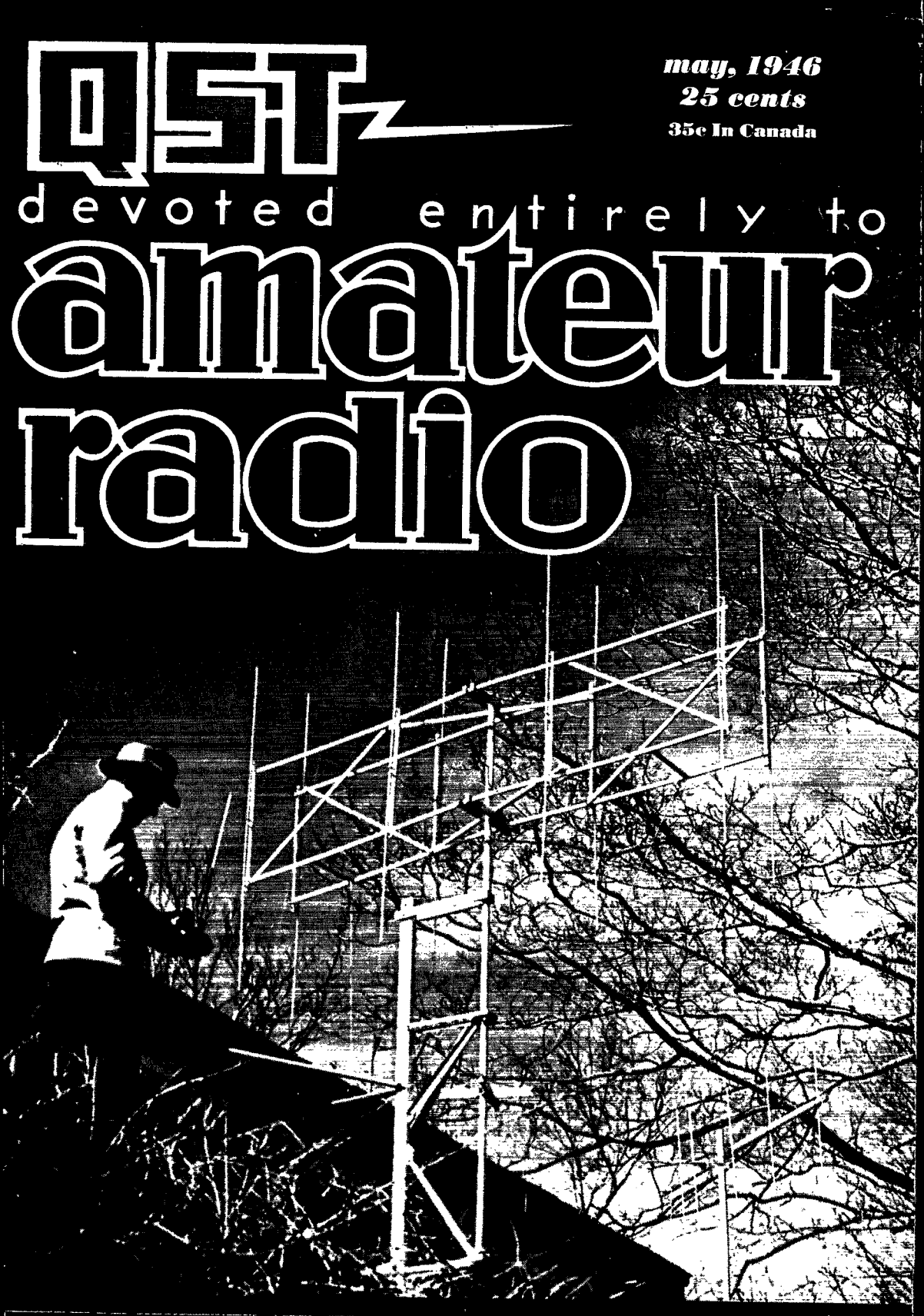
QST

may, 1946
25 cents
35c In Canada

devoted entirely to

amateur radio



PUBLISHED BY THE AMERICAN RADIO RELAY LEAGUE

A DX Record: To the Moon and Back

How the Moon-Radar Feat was Accomplished

BY HERBERT KAUFFMAN,* W2OQU

• In late January the newspapers and radio were full of the latest news sensation — "communication" with the moon. Lots of people had dreamed about it, but the practical realization came about as the result of hard work on the part of engineers at the Signal Corps Laboratories. There were hams in the picture, naturally. Here is the story of how it was done, written by the first man to hear a signal from the moon.

MAN HAS long dreamed of communicating with one of the heavenly bodies such as Mars or Venus or — more reasonably — the moon. The coming of radio and radar has given such encouragement to that dream that now — although the planets remain for the present unattainable — we *have* sent a radar pulse to the moon and received the echo back here on earth.

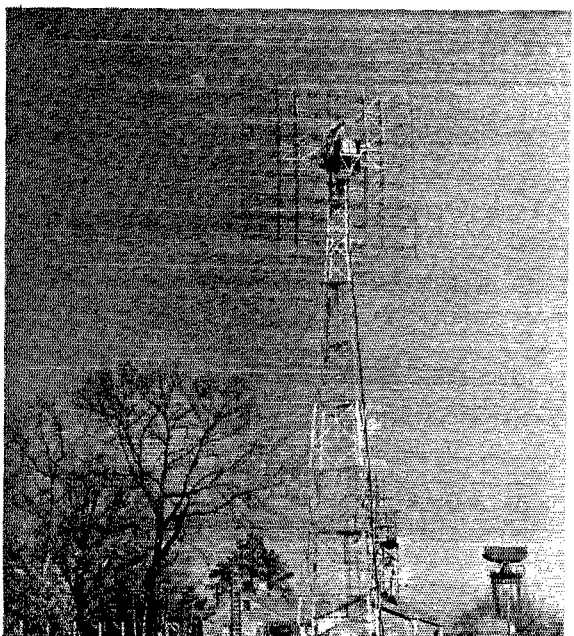
At the Evans Signal Laboratory, one of the combined group of Government laboratories comprising the Signal Corps Engineering Laboratories with headquarters at Bradley Beach, New Jersey, a ¼-second pulse of 111.5-Mc. energy was beamed at the moon on the 10th of January, 1946. Two and one-half seconds later a faint "beep" was heard in the loud speaker. That was the voice of the moon, the first time it had been heard upon the earth, and the writer was fortunate enough to be the first man to hear it.

It came about this way. Dr. Harold Webb, one of my associates, was watching the oscilloscope at the time. He had not heard the beep. I said to him, "Did you hear that beat?" He said, "No." Then I heard another beat, but Dr. Webb did not hear that either, so we turned up the audio gain, whereupon we both had no difficulty in hearing it.

At first we told no one of our success, not even Lt. Col. John H. DeWitt, jr., W4ERI and ex-W4FU, the officer in charge of the project and the man primarily responsible for the triumphant culmination of an experiment that many thought would never be successful. But the next day our results were confirmed; four other persons saw and heard moon echoes and Col. DeWitt was told that his plans and calculations had borne fruit at last.

The first question reasonably asked may be, "How do you know it is the moon?" Later on we will show that under the circumstances it *had* to be the moon, because the technical characteristics of the system would not allow a radar echo to return from anything except an object such as the moon, and at a distance of about 240,000 miles or so from the earth. It is possible that many people may still be skeptical, and to such folks I can only say that since that memorable day of January 10, 1946, we have received echoes day after day, at all hours of the day and night, and under all sorts of meteorological conditions. I do not mean we have received echoes without fail, every time we shot for the moon. We have not; indeed, that is one of the reasons for the continuation of the study. We want to find out *why* we do not, and what frequency or frequencies (if any) will make echoes receivable all the time.

In May, 1940, Col. DeWitt was chief engineer of WSM in Nashville, Tennessee. With typical amateur inquisitiveness he kept thinking about getting echoes from the moon and actually set up equipment using the same frequency and about the same power we use now. However, because of equipment limitations he failed to



Decidedly not a back-yard antenna, the directive system used in the moon-signal experiments has a power gain of 200 and uses 64 phased dipoles. The transmitter and receiving equipment is housed in the buildings at the foot of the tower.

* 15 Garfield Ave., Avon-by-the-Sea, New Jersey.

achieve success. The idea remained with him all during the war, but as director of the Evans Signal Laboratory the more pressing need for getting vital radar equipment out into the field made it impossible for him to try again.

Shortly after V-J Day, Col. DeWitt issued instructions to modify certain standard radar equipment for the moon investigation. Changes were made immediately to allow us to send out a long pulse. The transmitter was driven as hard as possible so we could get considerably more power from it, and an ordinary telegraph key was connected in the circuit to turn it on and off.

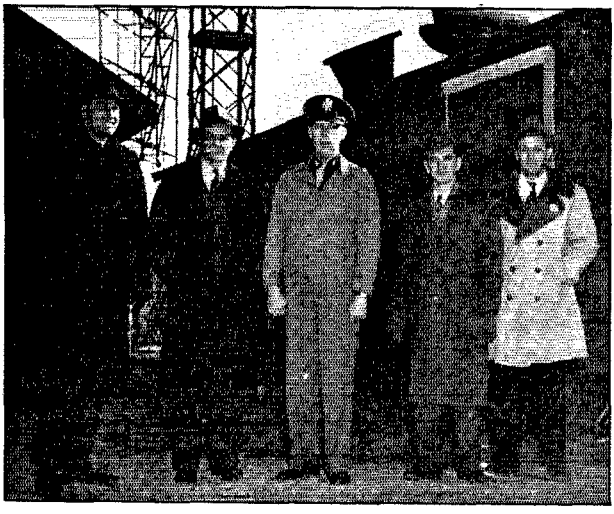
In a few days we were ready. It was decided that a one-second pulse every four seconds would be satisfactory, so about ten minutes before moonrise I started to key the transmitter, continuing for thirty minutes with no observable results. After operating for about ten days, it became evident that the TR system [1] was not working satisfactorily; the TR tubes were not protecting the receiver from the strong transmitted pulse. Engineers from the Antenna Design Section were called in, and J. Ruze, head of the section, and A. Kampinsky designed a system using quarter-wave step-up transformers on the 250-ohm line with open spark gaps on the ends of the quarter-wave TR and ATR. But the gaps would not last because of the unusually long pulses, although normally they work very well on conventional radar sets where the pulses are very short and the average power is low.

The next step was to design a mechanical TR system using an electro-mechanical keyer which would close shorting bars on the transmission line, the keying being so arranged that the shorting bars would have to be closed before the transmitter would go on. But still we did not succeed in getting a response from the moon.

The head of the Research Section of the Laboratory, E. K. Stodola, W3IYF, and two of his assistants, Dr. Harold Webb and J. Mofensen, now part of the moon-radar group, decided that if two antennas could be mounted side by side on the same tower the additional 6 db. gain that could be realized in the two-way system would be an advantage, so engineers from the Mechanical Design Section were consulted. Under the able direction of J. Zorowitz this rather difficult feat was accomplished. Now instead of 32 dipoles we had 64. The phasing of the dipoles was done by F. Haacke, P. Hartman and F. Elacker, ex-W2DMD.

During the time that the new antenna was being assembled and installed it was decided to utilize the narrowest band-pass possible in the receiver, to design an electronic keyer and sweep generator in order to operate a nine-inch cathode ray oscilloscope, and to measure the receiver sensitivity. Elaborate equipment was brought into the test area for the latter purpose and it was found that 0.04 microvolts would equal the receiver noise, showing that the receiver was many times more sensitive than our ham receivers — although it should be noted that the band-width used (about 50 cycles) is much too narrow for voice communication. Equipment was also set up to measure the efficiency of the transmitter, which was found to be fifty per cent. The power input to the final stage of the transmitter was about 8000 watts, so that 4000 watts went into the antenna. Since the antenna had a power gain of 200, this was equivalent to 800,000 watts in a nondirectional antenna. Calculations made in the labora-

[1] The automatic transmit-receive switching system used in radar sets. It normally employs gas tubes that ionize during the transmitted pulse, acting as a temporary conductor to change the transmission-line or wave-guide configuration in such a way that the receiver is protected during the time the transmitter is operating. At the end of the pulse the tubes deionize, opening the channel to the receiver.



Here's the group that holds the new DX record. Left to right, J. Mofensen, Dr. H. Webb, Lt. Col. J. H. DeWitt, ex-W4FU, E. K. Stodola, W3IYF, H. P. Kauffman, W2OQU.

tory by W. McAfee and his Mathematical Analysis Section showed that theoretically, using the above figures, the moon would reradiate 3 watts. It was calculated that the received signal after passing through the sensitive receiver would be about 16 db. above the noise.

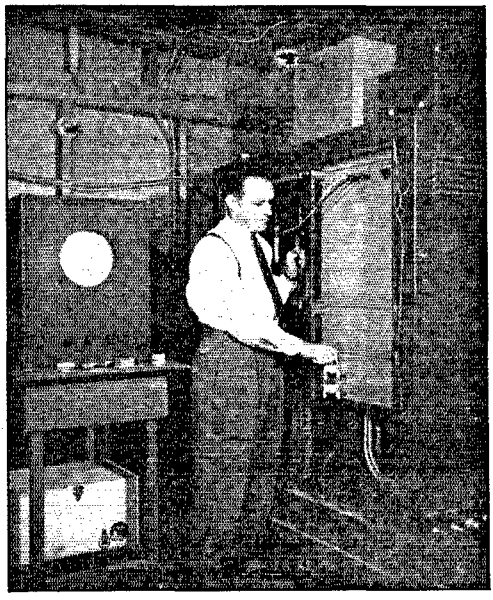
Tests were made daily after the new antenna and keyer were installed, without success until January 10 when I heard that first faint beep from the speaker.

To appreciate the techniques used it is necessary to understand the Doppler effect. Have you stood near a railroad while a train came thundering down the track with its whistle blowing? Did you notice that the sound suddenly dropped in pitch (or frequency) as the engine went by? That is a familiar example of the Doppler effect. If the source of waves, either sound or radio, moves with respect to the observer, the frequency will be shifted either higher or lower, depending on whether the object is approaching or receding. The amount of shift depends on the frequency used and the speed of the source with respect to the receiver. The effect is the same when the waves travel out from the source and are reflected back from a moving object. In our case the moving reflector is the moon, with additional movement contributed by the rotation of the earth.

To receive an echo from the moon obviously is not just a matter of turning on the transmitter and receiver and waiting. The exact time of moonrise or moonset at Belmar, N. J., where the equipment is located, must be computed daily, as must also the optical angle of rise or set on the horizon. The latter changes from day to day and varies about fifty degrees during the month. The orbital velocity of the moon, which also changes from day to day, must likewise be calculated and added to or subtracted from the earth's tangential speed so that the Doppler shift can be computed. The change in frequency caused by the Doppler effect is about 33 cycles per hundred-miles-per-hour of object speed at a frequency of 111 Mc. It is necessary for us to know this change so the receiver tuning can be set to pass the received frequency through the narrow band-pass.

Referring to the block diagram, Fig. 1, notice that the transmitter and a major portion of the receiver are both controlled by the same crystal, which has a fundamental frequency of 516.2 kc. This frequency is multiplied up to 12.39 Mc. as can be seen by following the arrows through the various blocks. At this point the signal is keyed by an electronic keyer and then goes through a coaxial line to the transmitter. All the stages preceding the keyer function continuously; this is necessary because frequencies are taken from the multiplier to operate the receiver heterodynes, and the receiver must operate during the time the transmitter is silent.

The 12.39 Mc. signal is fed to an 807 tripler which drives a pair of 257-B buffers in push-pull.



The author adjusting one of the receiver controls — the variable air-gap crystal holder that sets the fourth heterodyne to the proper frequency to compensate for Doppler effect.

These in turn drive a pair of 450-TH push-pull triplers which excite a pair of 1000-Ts as push-pull final amplifiers, feeding a balanced 250-ohm open line to the antenna. The standing-wave ratio on this line is less than 1.1 to 1.

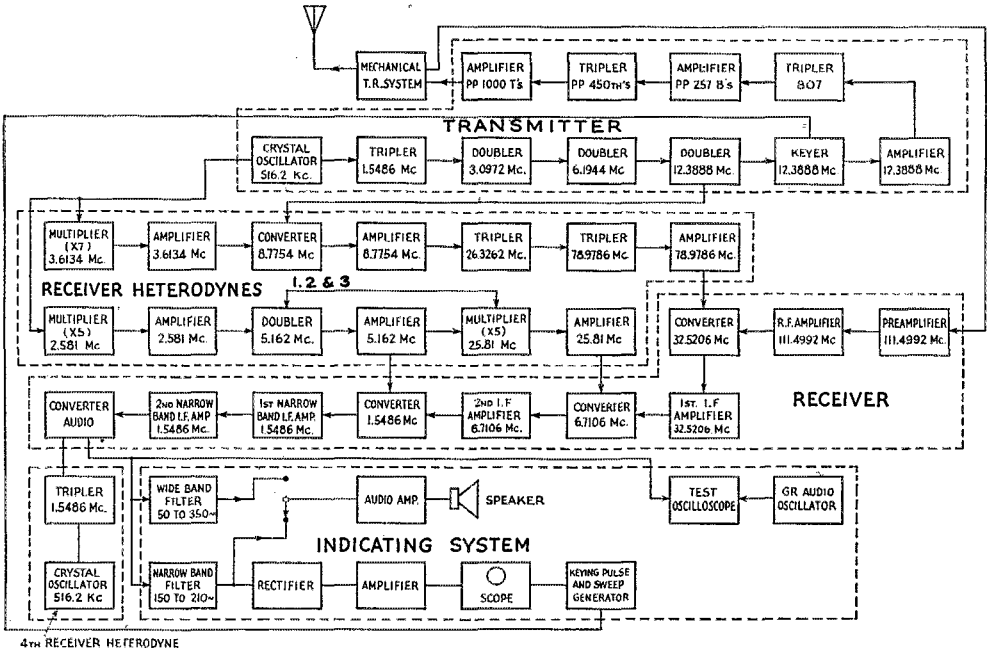
It might be pointed out here that the grid and plate tank circuits of the 807 and the 257-B tubes use conventional coils and condensers and that the grid circuit of the 450-THs also is coil-and-condenser tuned. However, the plate circuit of this stage and the grid and plate circuits of the 1000-Ts are parallel lines with movable shorts for tuning them to resonance.

The receiver, which employs a quadruple heterodyne circuit, obtains its heterodyne injection voltages from a separate series of multipliers working from the transmitter crystal. In fact, the receiver basic frequency is obtained from the transmitter multiplier, as can be seen by following the arrows on the block diagram. The injection for the last mixer is obtained from a separate crystal operating at a fundamental frequency of 516.265 kc., multiplied three times before it is injected into the last mixer. The frequency can be varied 400 cycles above or below the 1.545 Mc. last intermediate frequency by adjusting the air gap on the crystal holder. This variable crystal is necessary so that the injection to the last mixer can be set quite exactly to give a resultant final intermediate frequency of 180 cycles, because at this very low intermediate frequency the narrow band-pass filter is only 50 cycles wide. The beat between the incoming signal and this variable

crystal is so adjusted that the resultant beat falls in the center of the narrow-band filter. As explained, the Doppler shift changes from day to day and from moonrise to moonset, so it is necessary to adjust the last heterodyne injection frequency to compensate for this change.

To show how this crystal is set let us assume that the next moonrise will give a Doppler shift of 296 cycles. To this figure we add 180 cycles, a distance of more than 44,000 miles, because the one-quarter second pulse sent out into space is 44,000 miles long, as compared a pulse length of a few hundred yards with the usual aircraft-detection radars. The received signal follows the transmitted pulse by about 2.5 seconds, which is equal to about 235,000 radar miles (one direction only).

At the present time an old radar set using



Block diagram of the equipment used in the tests. The transmitter and receiver are both controlled by the same crystal.

which is the center of the band-pass filter of the final i.f. amplifier. This gives a resultant frequency of 476 cycles. We then compare an accurate audio oscillator with the heterodyne between the third harmonics of the two crystals by observing the audio frequency, which has been set to 476 cycles, on one set of plates of an oscilloscope and the heterodyne beat on the other set of plates. The crystal is adjusted until a 1-to-1 Lissajous pattern is observed on the 'scope. With this adjustment only an object moving at the proper speed to shift the carrier frequency by 296 cycles will be able to pass through the narrow band-pass of the receiver.

Now let us see why it was the moon that we received and not any other object. From the above analysis, any other object in space would have to be moving at the exact speed for which the receiver has been adjusted. Another object moving either faster or slower than the moon would create a different audio frequency and would not pass through the narrow band-pass filter if the difference was more than 50 cycles. Furthermore, such an object would have to be at

water-cooled tubes is being modified with Clarence Holritz, W9BBD/2, making the necessary calculations as to efficiency, bias and drive necessary to get an expected 50,000 watts output — more than ten times the power obtained from the present transmitter. The present low-power transmitter will be used as a driver. A high-voltage rectifier has been acquired from one of the other Sections of the Laboratory and this rectifier is capable of delivering 10,000 volts at 10 amperes continuously. The present low-power transmitter is being operated with about 4300 volts at 2 amperes to the final tubes. It is expected that much useful information will be gathered during the coming months in our studies of wave propagation — information which someday may be useful to the amateur. It is hoped, too, to study propagation at other frequencies than the one used so far.

Beyond the individuals mentioned above, so many have been associated with the "Diana" project that it is impossible to name all those who contributed to its success.